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Review

Review of solar refrigeration and cooling systems

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ABSTRACT

Providing cooling by utilizing renewable energy such as solar energy is a key solution to the energy and environmental issues. This paper provides a detailed review of different solar refrigeration and cooling methods. There are presented theoretical basis and practical applications for cooling systems within various working fluids assisted by solar energy and their recent advances. Thermally powered refrigeration technologies are classified into two categories: sorption technology (open systems or closed systems) and thermo-mechanical technology (ejector system). Solid and liquid desiccant cycles represent the open system. The liquid desiccant system has a higher thermal coefficient of performance (COP) than the solid desiccant system. Absorption and adsorption technologies represent the closed system. The adsorption cooling typically needs lower heat source temperatures than the absorption cooling. Based on COP, the absorption systems are preferred to the adsorption systems, the higher temperature issues can be easily handled with solar adsorption systems. The ejector system represents the thermo-mechanical cooling, and has a higher thermal COP but require a higher heat source temperature than other systems. The study also refers to solar hybrid cooling systems with heterogeneous composite pairs, to a comparison of various solar cooling systems, and to some use suggestions of these systems.

Contents

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1. Introduction

Energy security is the ability of a nation to deliver the energy resources needed to ensure its welfare and implies secure supply and stable prices. Energy is vital for progress and development of a nation's economy. The economic growth and technological advancement of every country depends on it [1] and the amount of available energy reflects that country's quality of life. Economy, population and per capita energy consumption have caused the increase in demand for energy during the last few decades. Fossil fuels continue to supply much of the energy used worldwide, and oil remains the primary energy sources. Therefore, fossil fuels are the major contributor to global warming. Along with the global warming impacts and climate changes, the demands for air-conditioning and refrigeration have increased.

Encouraged by the successful worldwide effort to protect the ozone layer, scientists and engineers have been committed to minimize and reverse the harming environmental effects of global warming. Global warming occurs when carbon dioxide, released mostly from the burning of fossil fuels (oil, natural gas, and coal) and other gases, such as methane, nitrous oxide, ozone, chlorofluorocarbons (CFCs), hydro-chlorofluorocarbons (HCFCs) and water vapour, accumulate in the lower atmosphere. As results of the rapid growth in world population and the economy total world energy consumption is projected to increase by 71% from 2003 to 2030 [2]. The awareness of global warming has been intensified in recent times and has reinvigorated the search for energy sources that are independent of fossil fuels and contribute less to global warming.

The Vienna Convention for the Protection of the Ozone Layer (1985), the Kyoto Protocol on Global Warming (1998) and the five amendments of the Montreal Protocol (1987) all discussed the reduction of CFCs to protect the ozonosphere, but the situation continues to decline. The European Commission (EC) Regulation 2037/2000, implemented on 1 October 2000, works to control and schedule all the ozone depleting materials; all HCFCs will be prohibited by 2015 [3,4].

The European strategy to decrease the energy dependence rests on two objectives: the diversification of the various sources of supply and policies to control consumption. The key to diversification is renewable energy sources (RES), because they have significant potential to contribute to a sustainable development [5].

1.1. Renewable energy

The term "renewable energy" refers to energy that is produced from natural resource having the characteristics of inexhaustibility over time and natural renewability. Renewable energy sources include wind, solar, geothermal, biomass and hydro energies [6]. An efficient utilization of renewable resources has a significant potential in both stimulating the economy and reducing pollution. Thus, many governments started to implement various policies that support renewable generation. One of the key components of any renewable energy policy is setting of renewable energy targets [7].

There have been numerous efforts undertaken by developed countries to implement different renewable energy technologies. The use of wind energy has increased over the last few years [8]. For example, the Netherlands, Germany, India and Malaysia are using wind turbines for producing electricity [9]. In north-western Iran, mineral materials are used for the production of geothermal energy and in Iceland, seventy percent (70%) or their factories utilize geothermal energy for industrial purposes [10].

Although Romania has a high potential of renewable energy sources, in 2010 the RES share in final energy consumption was 23.4%. Anyway, Romania ranked the second place in the European Union concerning the share of energy from renewable sources gross final consumption between 2006 and 2010 [11]

Among the energy sources alternative to fossil fuels, renewable energy sources such as solar and wind are the more available.

1.2. Solar energy

In recent years, scientists have increasingly paid more attention to solar energy. There is a sudden demand in the utilization of solar energy for various applications such as water heating, building heating/cooling, cooking, power generation and refrigeration [12].

Solar energy is the result of electromagnetic radiation released from the Sun by the thermonuclear reactions occurring inside its core. All of the energy resources on earth originate from the sun (directly or indirectly), except for nuclear, tidal and geothermal energy. The sun actually transmits a vast amount of solar energy to the surface of the earth [13]. The term "solar constant" signifies the radiation influx of solar energy. The mean value of solar constant is equal to 1368 W/m^2 [14].

In Romania the annual solar energy flow ranges between 1000–1300 kWh/m^2/year in more than half of the country. This climate allows the operation of solar collectors from March until October, with conversion efficiency between 40% and 90% [15]. Thus, an important solar potential exist.

Most countries are now accepting that solar energy has enormous potential because of its cleanliness, low price and natural availability. For example, it is being used commercially in solar power plants. Sweden has been operating a solar power plant since 2001. Romania's experience in solar energy represents a competitive advantage for the future development of this area, the country being a pioneer in this field. Between 1970 and 1980 were installed around 800,000 m^2 of solar collectors that placed the country third worldwide in the total surface of photovoltaic cells. Between 1984 and 1985 was achieved the peak of solar installations, but after 1990 unfavourable macroeconomic developments led to the abandonment of the production and investments in the solar energy field. Today about 10% of the former installed collector area is still in operation [16].

In recent years, many countries have been facing difficulties with the issue of refrigeration systems. Specifically, the demand of air conditioning for both commercial and residential buildings during the summer is ever-increasing [13]. There is a lack of electricity and storage in developing countries to accommodate high energy consumptive systems such as refrigeration and cooling.

The solar cooling techniques can reduce the environmental impact and the energy consumption issues raised by conventional refrigeration and air-conditioning systems. Therefore, in this paper are presented theoretical basis and practical applications for cooling technologies within various working fluids assisted by solar energy and their recent advances. Also, a comparison of various solar cooling systems is performed and some suggestions about the use of these systems are given.

2. Solar refrigeration technology

Solar refrigeration offers a wide variety of cooling techniques powered by solar collector-based thermally driven cycles and photovoltaic (PV)-based electrical cooling systems. Fig. 1 shows a schematic diagram of a solar thermal cooling system. The solar collection and storage system consists of a solar collector (SC) connected through pipes to the heat storage. Solar collectors transform solar radiation into heat and transfer that heat to the heat transfer fluid in the collector. The fluid is then stored in a thermal storage tank (ST) to be subsequently utilized for various applications. The thermal AC (air-conditioning) unit is run by the hot refrigerant coming from the storage tank, and the refrigerant circulates